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WO 2001/000285 A1
US 5846139 A
US 5626526 A
US 5481355 A
US 5863255 A
US 5700204 A
US 5486002 A
US 5401026 A

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(54) Abstract Title
Golf ball tracking device and method

(57) A device and method of analysing movement of a golf ball by transmitting 9 radiation towards an area expected to lie in the path of the golf ball, receiving 11,13,15 reflected radiation and using a signal derived therefrom to determine the velocity and angular deviation of the golf ball trajectory. Preferably the velocity is determined by measuring the Doppler shift of the radiation. Optionally the path length difference or the phase difference of the received radiation may be determined. The device and method may include means of detecting when the golf ball is struck by a golf club.

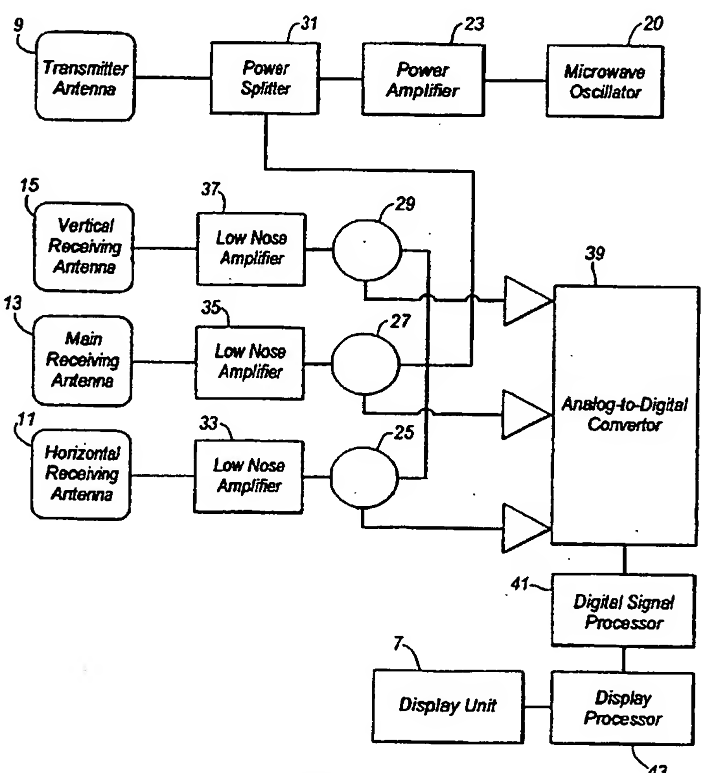

Fig.5

At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

The print reflects an assignment of the application under the provisions of Section 30 of the Patents Act 1977.

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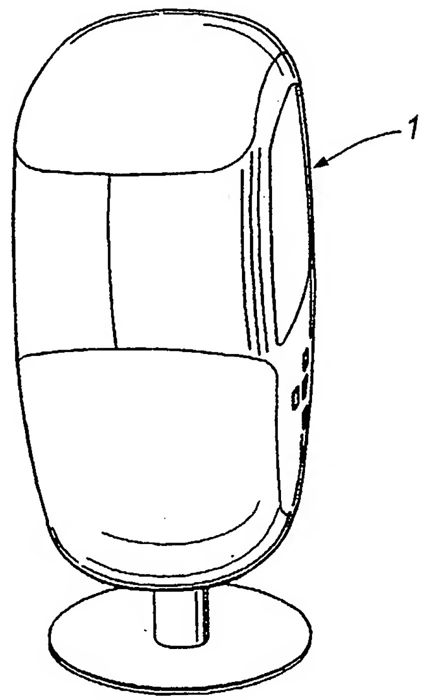

Fig.1

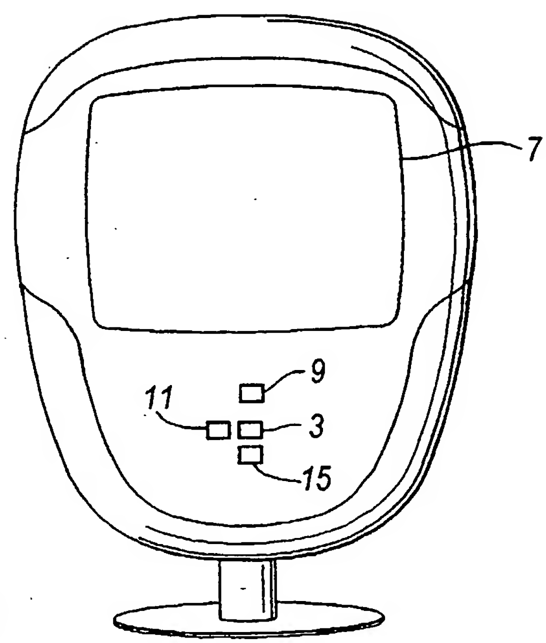

Fig.2

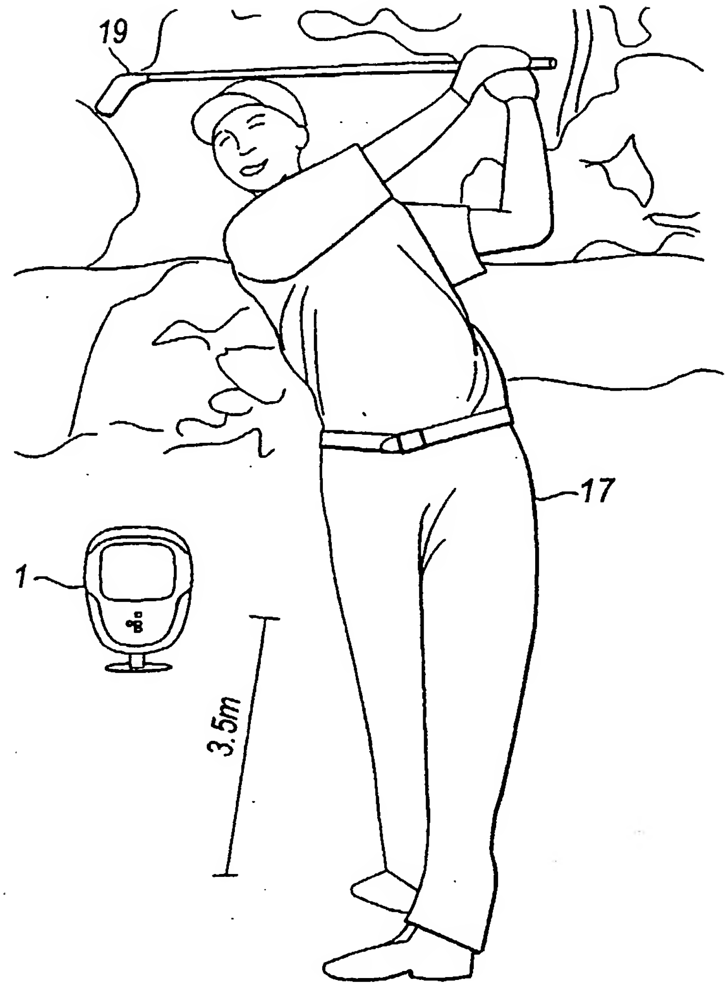

Fig.3

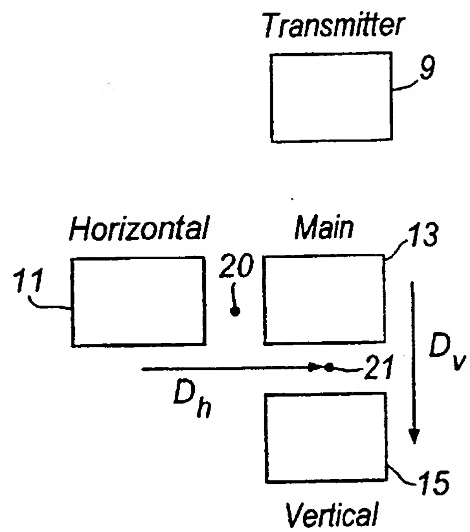
Transmitter
9
Horizontal
Main
13
11
20
D_v
D_h
21
15
Vertical

Fig.4

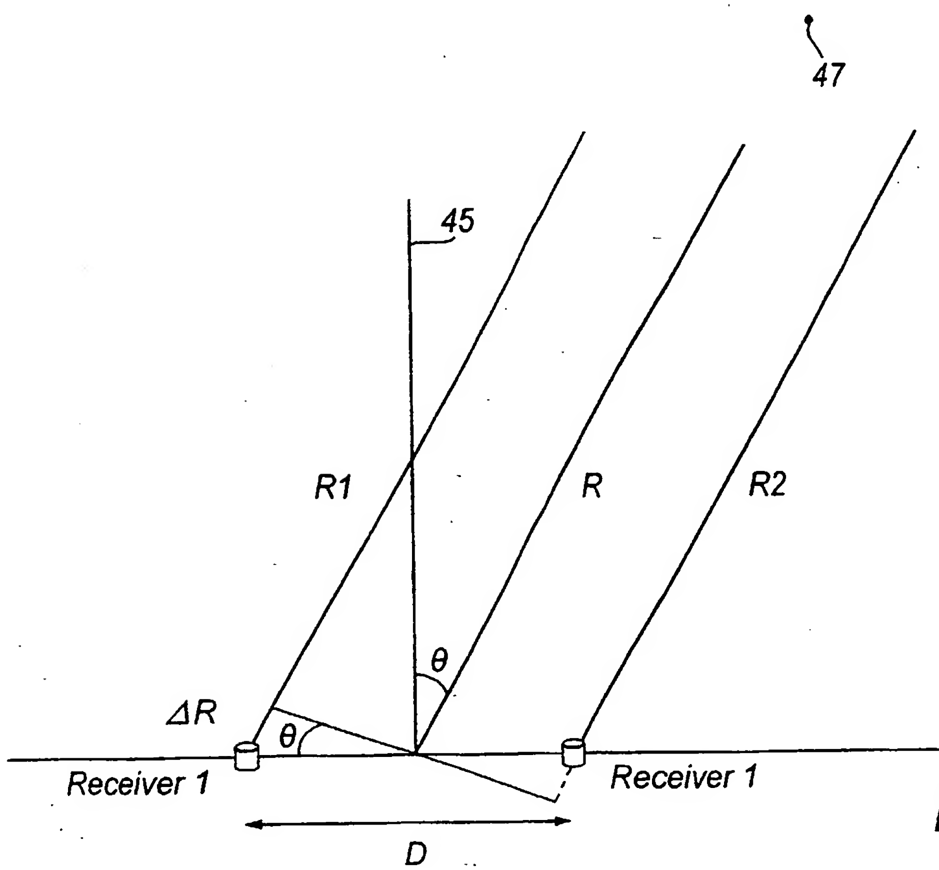
47
45
R1
R
R2
θ
ΔR
θ
Receiver 1
Receiver 1
D

Fig.6

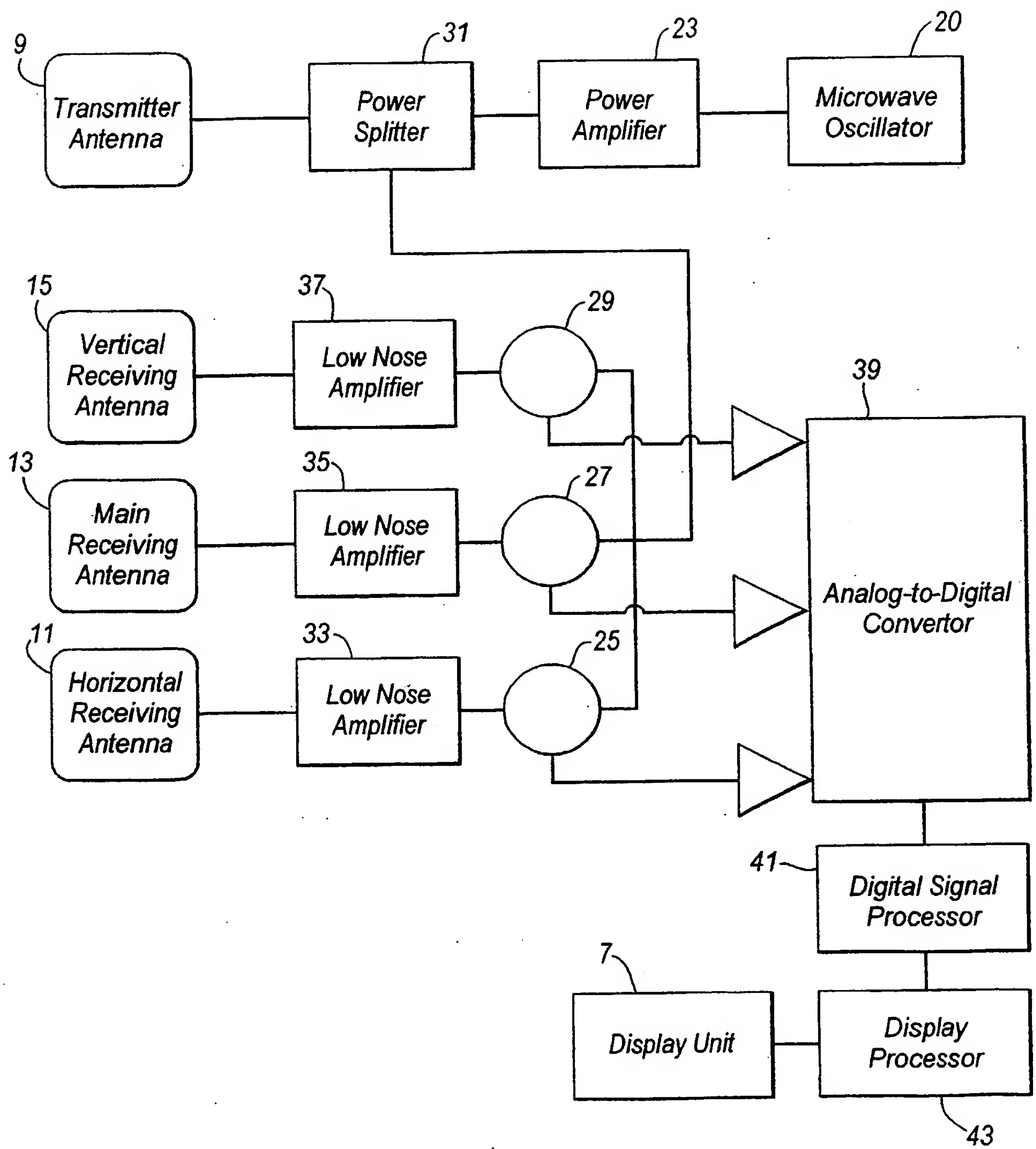
9
Transmitter Antenna
31
Power Splitter
23
Power Amplifier
20
Microwave Oscillator
15
Vertical Receiving Antenna
37
Low Nose Amplifier
29
13
Main Receiving Antenna
35
Low Nose Amplifier
27
11
Horizontal Receiving Antenna
33
Low Nose Amplifier
25
39
Analog-to-Digital Convertor
41
Digital Signal Processor
7
Display Unit
Display Processor
43

Fig.5

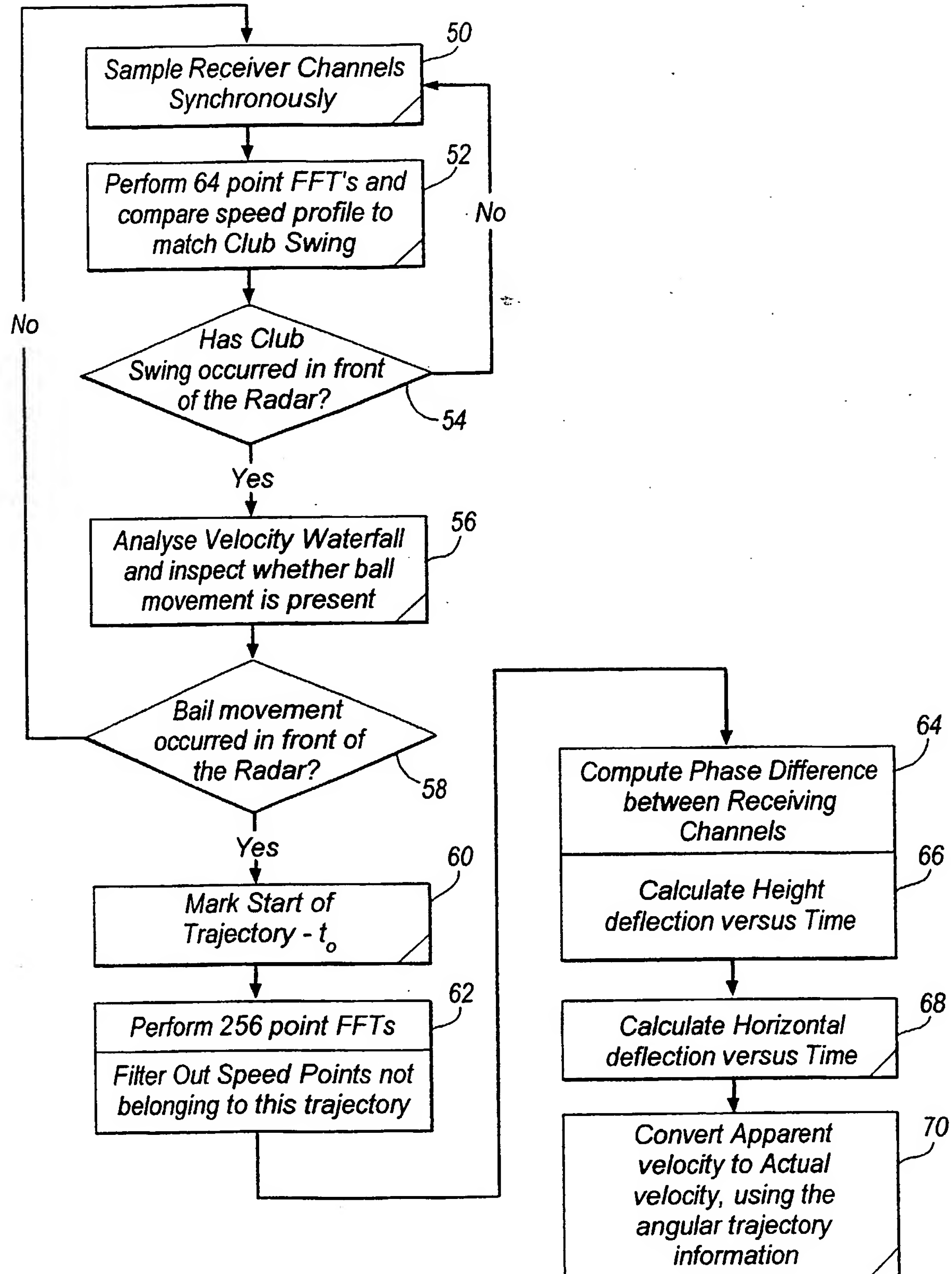
Sample Receiver Channels Synchronously
50
Perform 64 point FFT's and compare speed profile to match Club Swing
52
No
Has Club Swing occurred in front of the Radar?
54
Yes
No
Analyse Velocity Waterfall and inspect whether ball movement is present
56
Ball movement occurred in front of the Radar?
58
Yes
Mark Start of Trajectory - t_o
60
Perform 256 point FFTs
Filter Out Speed Points not belonging to this trajectory
62
Compute Phase Difference between Receiving Channels
64
Calculate Height deflection versus Time
66
Calculate Horizontal deflection versus Time
68
Convert Apparent velocity to Actual velocity, using the angular trajectory information
70

Fig.7

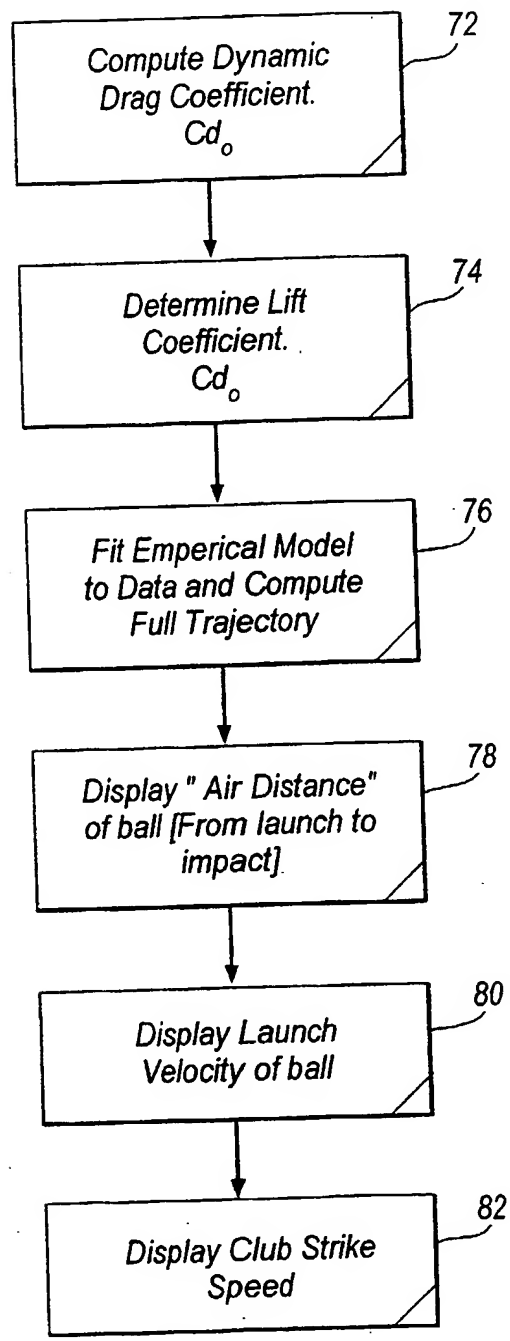
Compute Dynamic Drag Coefficient. Cd$_o$
72
Determine Lift Coefficient. Cd$_o$
74
Fit Emperical Model to Data and Compute Full Trajectory
76
Display " Air Distance" of ball [From launch to impact]
78
Display Launch Velocity of ball
80
Display Club Strike Speed
82

Fig.8

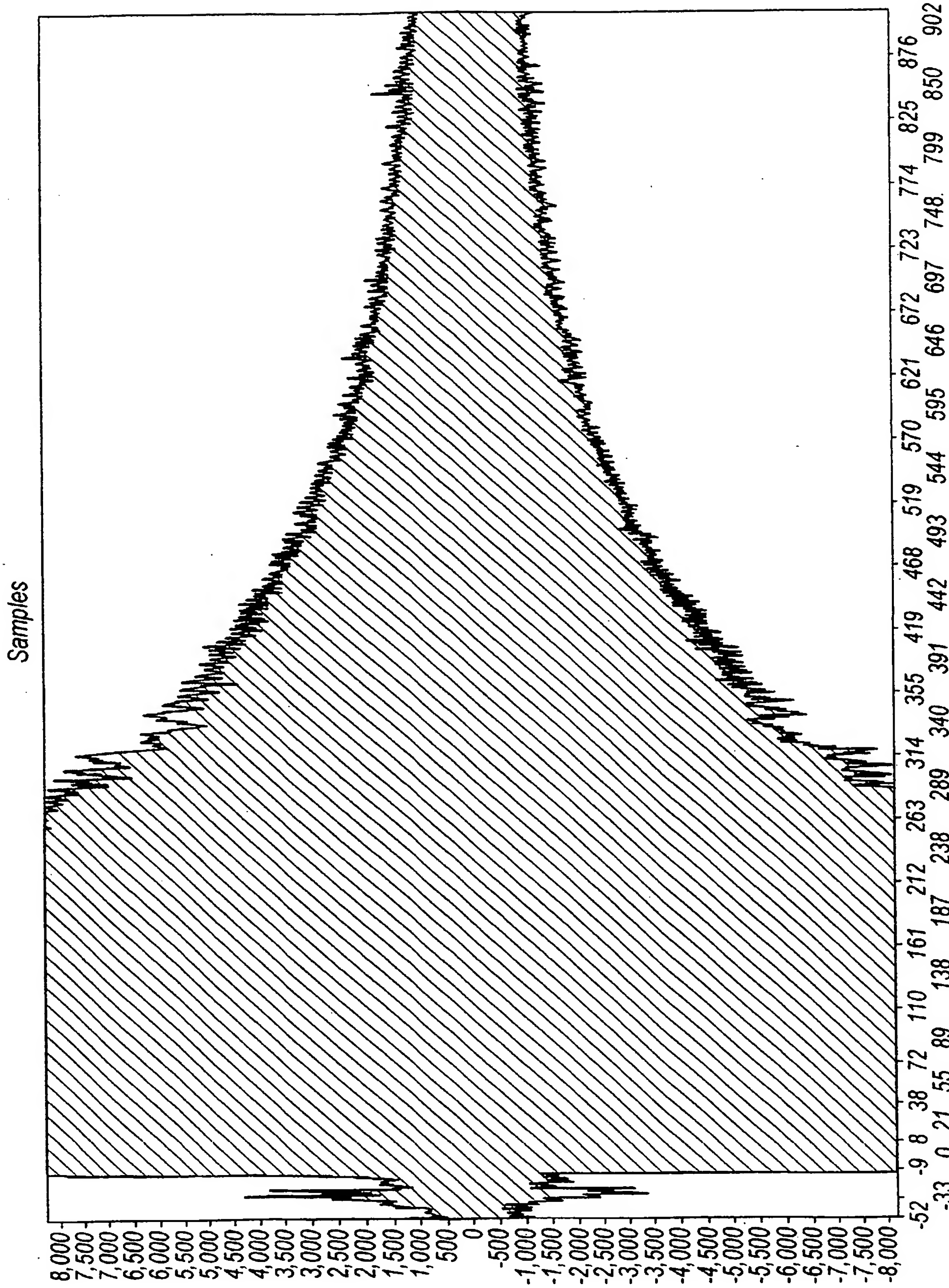
Samples
RECEIVED TIME SIGNALS VS TIME
8,000 7,500 7,000 6,500 6,000 5,500 5,000 4,500 4,000 3,500 3,000 2,500 2,000 1,500 1,000 500 0 -500 -1,000 -1,500 -2,000 -2,500 -3,000 -3,500 -4,000 -4,500 -5,000 -5,500 -6,000 -6,500 -7,000 -7,500 -8,000
-52 -33 -9 8 0 21 38 55 72 89 110 138 161 187 212 238 263 289 314 340 355 391 419 442 468 493 519 544 570 595 621 646 672 697 723 748 774 799 825 850 876 902

Fig.9

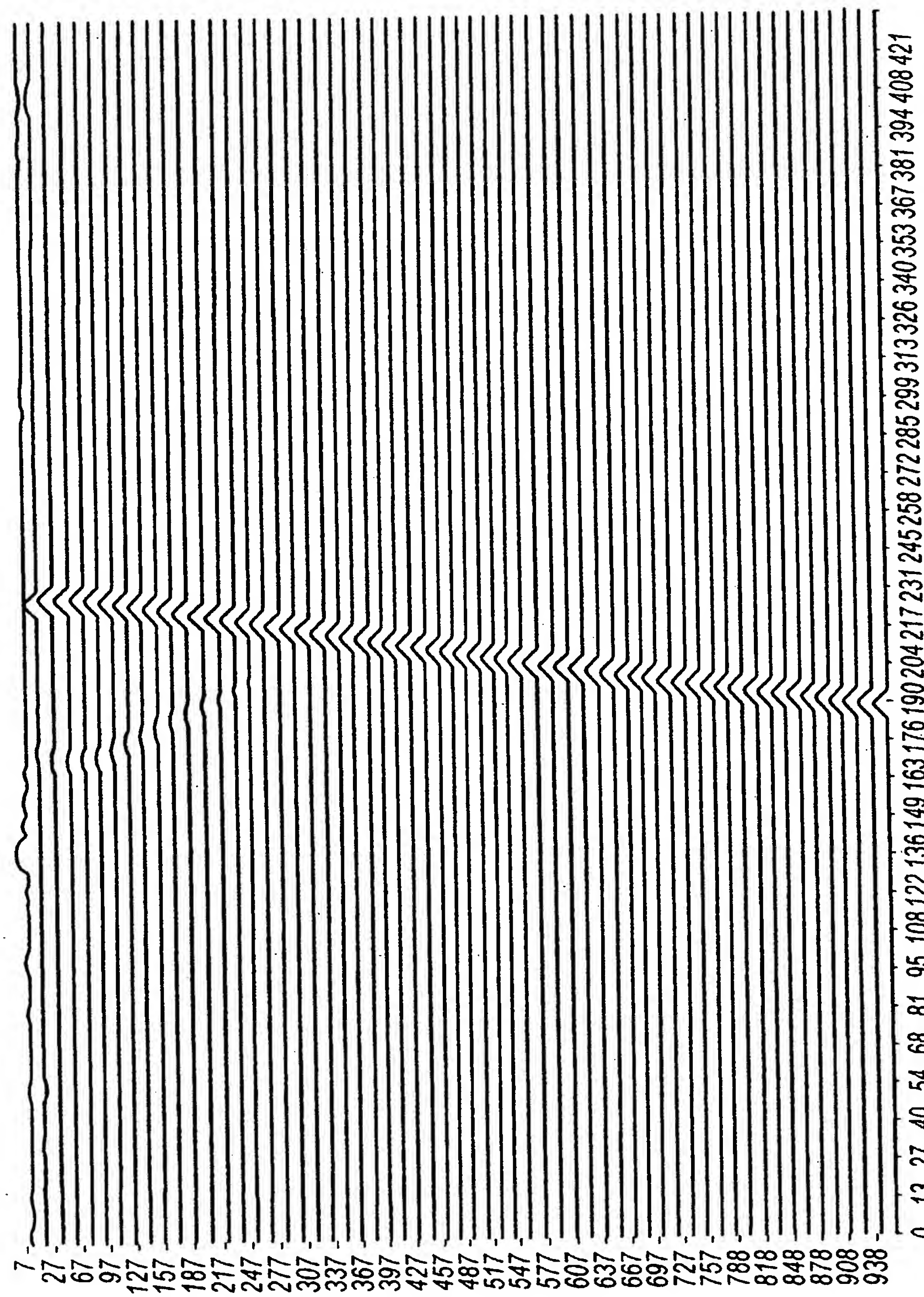
7 27 67 97 127 157 187 217 247 277 307 337 367 397 427 457 487 517 547 577 607 637 667 697 727 757 788 818 848 878 908 938
0 13 27 40 54 68 81 95 108 122 136 149 163 176 190 204 217 231 245 258 272 285 299 313 326 340 353 367 381 394 408 421

Fig.10

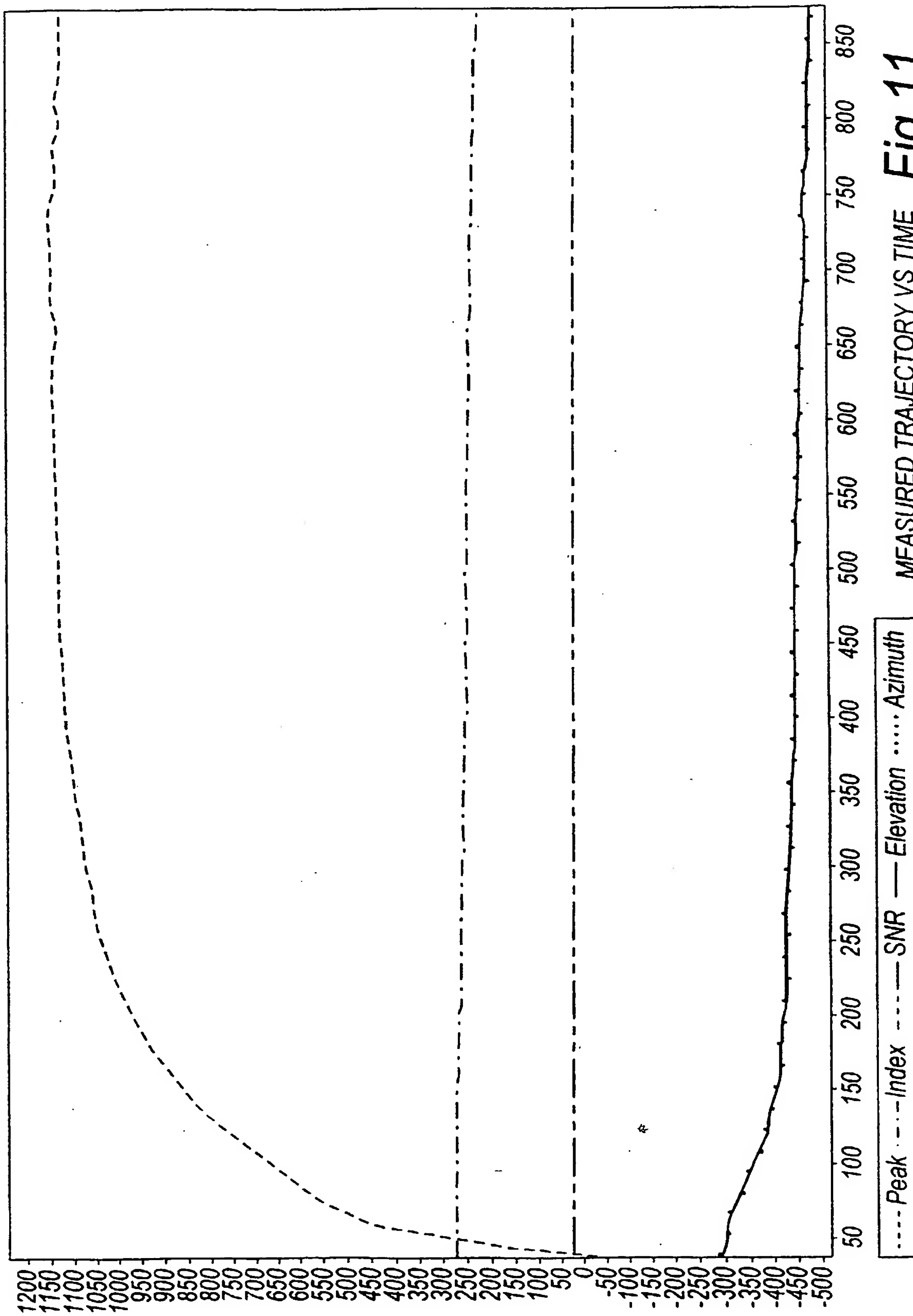
MEASURED TRAJECTORY VS TIME
---- Peak - - - Index - - - - SNR —— Elevation ····· Azimuth
1200 1150 1100 1050 1000 950 900 850 800 750 700 650 600 550 500 450 400 350 300 250 200 150 100 50 0 -50 -100 -150 -200 -250 -300 -350 -400 -450 -500
50 100 150 200 250 300 350 400 450 500 550 600 650 700 750 800 850

Fig.11

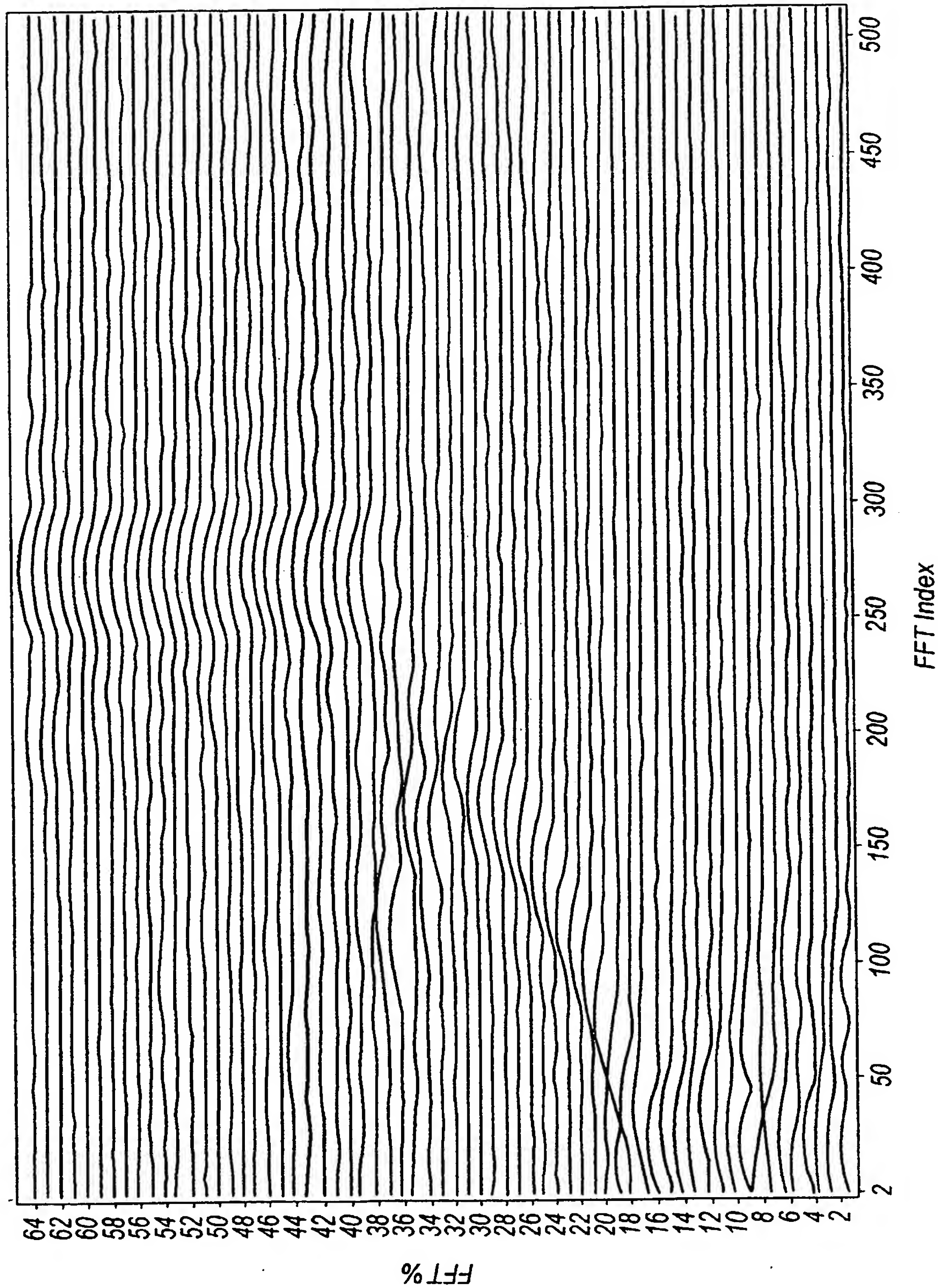
FFT Index
2
50
100
150
200
250
300
350
400
450
500
FFT%
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
52
54
56
58
60
62
64

Fig.12

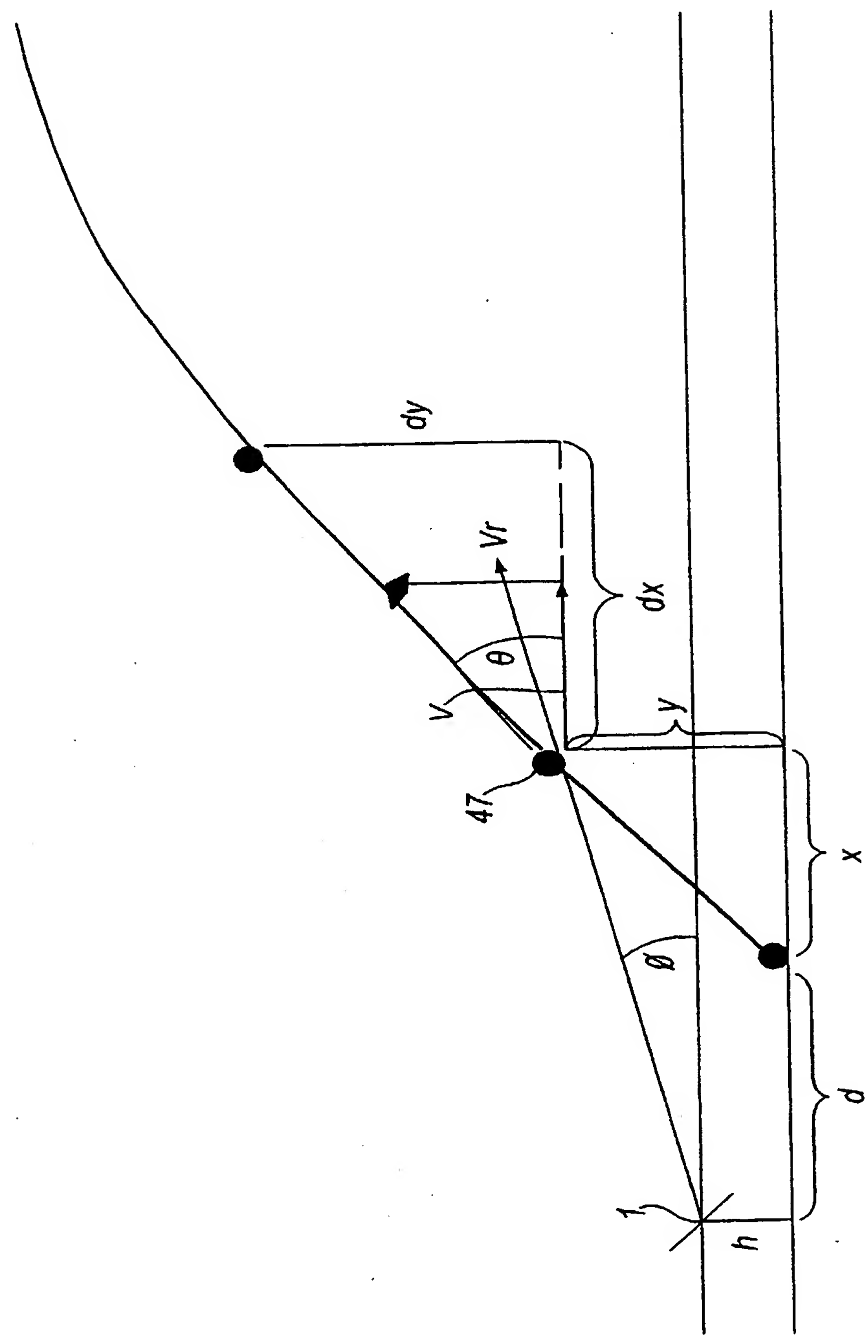

Fig.13

GOLF BALL TRACKING DEVICE

The present invention relates to a method and apparatus for analysing movement of a golf ball.

Systems are known for tracking golf balls hit by a golf club. For example, US patent No. 6179720 discloses an arrangement that matches the impact location of an object at or near a predetermined target with one of many shots at the target. US patent No. 5401026 relates to a Doppler radar system which is used to calculate the carry distance of a golf shot.

Radar devices which utilise the Doppler frequency shift to measure the velocity of a moving object are known in many applications. With such devices electromagnetic energy, such as microwave radar energy, is transmitted towards and reflected from a moving object. The energy undergoes a frequency shift, the magnitude of which is proportional to the velocity of the object relative to the transmitter. Samples of the transmitted and reflected radiation are mixed and processed to obtain a difference signal having a frequency which is equal to the difference between the transmitted and reflected frequencies, this difference being the Doppler shift. Once the difference frequency has been obtained, the relative velocity of the object can be readily calculated using known methods.

In addition to using Doppler radar for measuring characteristics of golf ball travel, other techniques have been devised, such as Doppler laser, sonar, light

gates and cameras, all having various degrees of accuracy. The most common approach is to use Doppler radar to measure the apparent speed of the golf ball directly from or towards the Doppler radar device. However, known Doppler radar devices suffer from a major problem in that no allowance is made for any deviation from the axis extending from or towards the radar device. This measurement of speed of the golf ball directly from or towards the Doppler radar device is hereinafter referred to as the "apparent velocity" of the golf ball. The measurement of the apparent velocity of a golf ball at launch, i.e. immediately after striking by the golf club, will provide only a very crude estimation of how far the golf ball will travel (the "carry distance").

It is an object of the present invention to provide a device with improved golf ball tracking.

According to a first aspect of the present invention, there is provided a method of analysing movement of a golf ball, the method including transmitting radiation towards a location expected to lie in the path of a golf ball; receiving reflected radiation and generating a signal representative thereof; processing the signal to derive a value indicative of the velocity of the golf ball in a predetermined direction; processing the signal to derive a value indicative of the angular deviation of the golf ball trajectory from the predetermined direction; and deriving from the velocity and deviation values an indication of the speed of the ball along its trajectory.

In the embodiment, the derivation of a value indicative of the velocity of the golf ball in a predetermined direction can be considered to correspond to the "apparent velocity" mentioned above. By additionally processing the signal to derive a value indicative of angular deviation of the golf ball trajectory from the predetermined direction as well, a much better indication of the speed of the golf ball along its trajectory can be derived.

In the embodiment the velocity of the golf ball in the predetermined direction is determined by measuring the Doppler shift in the radiation.

In the embodiment the step of receiving reflected radiation includes receiving radiation from at least two directions parallel to an axis. The step of receiving radiation advantageously further includes receiving radiation from at least one direction parallel to a further axis, different from the other axis. The two axes may be parallel.

The method advantageously includes analysing a signal generated from the received radiation and determining the angular deviation of the golf ball from the or each axis. By determining the angular deviation of the golf ball from two different axes, the speed and direction of golf ball travel can be calculated relatively accurately. Determining to angular deviation may include determining the path length difference of the received radiation, and ~~preferably includes determining the phase difference of~~ the received radiation.

Means for receiving radiation may be provided, being sensitive to radiation substantially within a 20° vertical field and a 10° horizontal field. The means for receiving radiation may be positioned substantially 190mm above ground level and between 3.3 and 3.5m behind the expected golf ball launch position.

The method preferably also includes detecting when the golf ball is struck by a golf club.

According to the embodiment, using accurate angular measurements along the ball trajectory, it is possible to correct the apparent speed of the golf ball obtained from the Doppler shift measurement to true speeds at any point along the trajectory. Regardless of the club used, or the prevailing atmospheric conditions, the actual trajectory is either measured in full, or the device characterises the dynamic behaviour of a particular golf ball during flight and hence making it possible to predict to within a couple of metres, reliably the carry distance of a golf ball.

According to a second aspect of the present invention, there is provided apparatus for analysing movement of a golf ball, the apparatus including means for transmitting radiation towards a location expected to lie in the path of a golf ball; means for receiving reflected radiation and generating a signal representative thereof; means for processing the signal to derive a value indicative of the velocity of the golf ball in a predetermined direction; means for processing the signal to derive a value

indicative of angular deviation of the golf ball trajectory from the predetermined direction; and means of deriving from the velocity and deviation values an indication of the speed of the golf ball along its trajectory.

For a better understanding of the present invention, an embodiment will now be described by way of example, with reference to the accompanying drawings, in which:-

Figure 1 shows a perspective view of a golf radar enclosure according to the present invention;

Figure 2 shows a front elevational view of the golf radar enclosure of Figure 1;

Figure 3 shows schematically how the golf radar enclosure will be positioned with respect to a golfer as he strikes the ball;

Figure 4 shows schematically the relative positions of the transmitter and receiver elements of the system;

Figure 5 shows an electronic functional block diagram of the system;

Figure 6 illustrates the principle for measuring angular deviation of the golf ball;

Figures 7 and 8 show process flow diagrams for tracking the golf ball;

Figure 9 shows a plot of an example signal received by a receiver of the system against time;

Figure 10 shows a plot of the velocity waterfall signal derived from one of the receivers;

Figure 11 shows a plot of the measured trajectory of the golf ball in elevation and azimuth against time;

Figure 12 shows a plot of the velocity waterfall signal indicating golf club movement; and

Figure 13 shows a golf ball trajectory.

In the figures like elements are generally designated with the same reference numeral.

Figures 1 and 2 show the golf radar enclosure 1. The enclosure 1 comprises front 3 and rear 5 main surfaces. The front surface includes a display unit 7, such as a liquid crystal display unit for displaying calculated data concerning a particular shot. A transmitter 9 and three receivers 11, 13 and 15 are positioned on the front surface 3. The enclosure 1 includes digital signal processing electronics, display processing electronics and a power supply (none of which are shown in Figures 1 and 2).

As shown in Figure 3, the enclosure 1 is positioned approximately 190mm above ground level and approximately 3.3 to 3.5 metres behind the position of a golfer 17 who is about to strike a golf ball, for example as he or she

tees off. The enclosure 1 is positioned directly behind the golf ball launch position. The enclosure 1 is oriented so that the front surface 3 faces the golf ball launch position.

Figure 4 shows schematically the arrangement of the transmitter 9 and the three receivers 11, 13 and 15 of the enclosure 1. Energy is transmitted towards the golf ball launch position by transmitter 9. The energy is reflected from every object within the field of view of the transmitting device 9. The golfer 17 striking a ball together with his or her club 19, as well as the ball struck and balls from other players are all potential reflectors of the transmitted energy. The receivers 11, 13 and 15 are synchronous receivers and measure the reflected energy from all targets within their fields of view. The transmitter and three receivers are generally placed in a particular pattern to optimise the signal quality from the golf ball and to minimise the negative influence from the golfer 17, swinging club 19 and any other sources of reflection.

The receivers 11, 13 and 15 are spaced apart by a predetermined distance. In order to measure the angular deviation of the golf ball from the vertical, receivers 13 and 15 are spaced apart vertically by a distance d_v. In order to measure the deviation from the horizontal, the receivers 11 and 13 are spaced apart horizontally by a distance d_h. The receiver pair 11, 13 have a sensor axis 20 extending out of the page in Figure 4, and the ~~receiver pair 13, 15 have a sensor axis 21,~~ also extending out of the page in Figure 4.

The antenna beamwidths are approximately 20 degrees in vertical and 10 degrees in the horizontal direction. The antenna beam widths used, as well as the placement relative to the golfer and the ground, are selected in order to minimise the effect of multipath and hence distortion of the relative phase measurements, which in turn reflect in the angular measurements.

It will be noted that, in this embodiment, the second receiver 13 contributes to angular deviation data from the horizontal and the vertical. This is a cost-effective arrangement. However, the second receiver 13 could be replaced with two separate receivers, a first receiver being dedicated to measure horizontal deviation with the receiver 11, and a second receiver dedicated to measuring vertical deviation with receiver 15.

Figure 5 shows schematically the components contained within the enclosure 1. A microwave oscillator 22 generates a signal of predetermined frequency, which is amplified by power amplifier 23. The amplified signal is passed to both the transmitter antenna 9 and to respective mixers 25, 27 and 29 by power splitter 31. As described above, reflected radiation is received by receiver antennae 11, 13 and 15. The signals from the receiving antennae 11, 13 and 15 are passed to respective low noise amplifiers 33, 35 and 27. The amplified signals are applied respectively to mixers 25, 27 and 29, where they are mixed with the amplified oscillating signal from the beam splitter 31. The mixed analogue signals are then converted to digital signals by analogue

to digital converter 39 and subsequently processed by signal processor 41. The outputs from the digital signal processor 41 are then configured by display processor 43 for presentation on the display 7 of the enclosure 1.

The operation of the apparatus will now be described. The description of how to obtain the "apparent velocity" will, however, be omitted for the sake of brevity, as this would be known to a person skilled in the art. As mentioned above, the apparent velocity differs from the actual speed. This difference can be described by the following formula:

Velocity(apparent) = Velocity(actual) x
cos(vertical ball angle - device pointing angle) x
cos(horizontal ball angle - device pointing angle)

For example, for a ball launched at 30° vertical deviation from axis 21 and 20° in azimuth deviation from axis 20 (the device pointing angle being 0° - zero in both cases), the error in the apparent velocity compared to the actual velocity would amount to approximately 18.7%.

The vertical ball angle is derived from the signals received at the main receiving antenna 13 and the vertical receiving antenna 15. The horizontal ball angle is derived from the signals received by the main receiving antenna 13 and horizontal receiving antenna 11. The interferometry principle used to track the ball will be described with reference to Figure 6, and is explained by the publication "Introduction to Monopulse", Donald R. Rhodes, PhD, which is incorporated herein by reference.

Figure 6 shows two receivers, which could correspond to receiver pair 11, 13 or receiver pair 11, 15. The receivers are spaced apart by a distance D and are directed along an axis 45, which correspond to axis 20 or 21. When the golf ball 47 is in a position deviated from the axis 45, the radiation R1 and R2 reflected from the golf ball 47 and received by "Receiver 1" and "Receiver 2" respectively will travel different distances to each of the respective receivers, the difference being ΔR.

Energy wave path length difference = $2\Delta R = D.\sin\theta$

The path length difference can be expressed as a proportion of the electrical wavelength

$$\Delta\varphi = (2\pi D/\lambda).\sin\theta$$

where $\Delta\varphi$ is the phase difference between the receiving channels,

λ is the wavelength of the energy transmitted by the transmitter 9 to determine the angles to the ball 47 trajectory,

θ is the angle in space relating to the electrical phase difference $\Delta\varphi$.

At any particular point the path length difference is a direct indication of the angle of arrival of the plane wave front, indicating the angle of deviation θ from the axis 45 of the receivers.

Figures 7 and 8 show the processes performed by the digital signal processor 41 and display processor 43. When the digital signal processor 41 is initiated it synchronously samples received data from each of the receivers 11, 13 and 15 at step 50. Figure 9 shows a typical time signal series as measured by any one of the three receivers 11, 13 or 15. By sampling the time signals from each of the receivers 11, 13 and 15 synchronously the relative phase information is preserved in the signals. Data is collected and recorded from the receivers 11, 13 and 15 continuously and simultaneous digital signal processing is performed on the recorded data to provide velocity and angular information of items within the field of view of the sensors at least every two to 15ms.

A 64 point fast furrier transform (FFT) is performed on the signals from the three receivers 11, 13 and 15 in real time to produce a velocity spectrum of all moving objects within the field of view of the receivers (step 52). At this stage the golf ball has not been struck and the digital signal processor 41 analyses the velocity spectra to identify when a golf club swing occurs, which is the trigger for measuring golf ball movement. The magnitude and tempo of a typical golf club swing is characteristic for a particular set up, which is mathematically modelled and used as a unique identification in order to eliminate triggering from neighbouring club swings, as well as balls which may come within the field of view of the receivers 11, 13 and 15. The magnitudes of the time signal of all three receivers are compared with a calibrated range of values to ensure

a valid trigger condition. In addition, the apparent velocity profile of the club is used a characteristic to validate the trigger condition. Finally, the angles both vertical and horizontal of the club swing are analysed to further validate the swing path as a conclusive method of verifying that a club swing has in fact occurred. Figure 10 shows typical club strike speed behaviour in the format of a velocity waterfall series. The trigger mechanism relies on the fact that the club's apparent rate as determined by the digital signal processor 41 is characteristic and lies between a minimum and maximum rate. The signal processor 41 measures the acceleration and deceleration of the club as it moves through the swing plane. If a golf ball is struck, the club as well as the ball appears as two moving objects, with the ball speed generally much higher than the club speed. The angular movement of the club face within the antenna beams is also measured, and hence a confirmation of the club swing trajectory is readily made as confirmation that a club swing has indeed taken place, right in front of the radar of concern and not introduced by neighbouring golfers, etc.

If the digital signal processor 41 determines that a club swing has not occurred at step 54, the digital signal processor 41 returns to step 50 and monitor for a club swing. However, if it is determined that a club swing has occurred the digital signal processor 41 performs step 56 which analyses velocity waterfall signals computed for each of the three receivers 11, 13 and 15. The relative velocity as measured from each of the three receivers is exactly the same. However, the phase

difference is extracted in the frequency domain and used for angular calculations (described later). Figure 10 shows a typical velocity waterfall plot. If the analysis of the velocity waterfall indicates that ball movement is not present the step 58 returns processing to step 50, where the signals from the receivers 11, 13 and 15 are sampled. However, if it is detected that ball movement has occurred step 60 identifies the start of the golf ball trajectory t_o. Step 62 then performs a 256 point FFT on the signals from the receivers 11, 13 and 15. An algorithm is used to filter out values calculated not to belong to the golf ball trajectory. At step 64 a 1024 point FFT is performed to extract the phase difference between the receiving channels 11, 13 and 15. At step 66 the deviation from the axis 21 of the receiver pair 13 and 15 is calculated. At step 68 the deviation from the axis 20 of the receiver pair 11, 13 is calculated. The calculations at step 66 and 68 are performed using the principle described in relation to Figure 6 various distances from the enclosure 1. Doppler shift information is also extracted in the conventional manner, and at step 70 the apparent velocity obtained by the Doppler shift method is used to provide actual velocity data using the angular trajectory information obtained at step 66 and 68.

Referring now to Figure 8, a mathematical model is used to extract the dynamic drag coefficient Cd_o at step 72 and the dynamic lift coefficient CL_o at step 74.

The dynamic drag and lift coefficients embody the ball physical properties, the wind and other atmospheric

conditions. The derivation of these coefficients allows, regardless of the club used and the prevailing atmospheric conditions, the dynamic behaviour of a particular golf ball strike to be characterised, hence making it possible to predict reliably to within a couple of metres the carry distance of a golf ball.

Ideally, the receivers 11, 13 and 15 would receive data relating to the entire golf ball trajectory from the initial strike by the club until the golf ball travel is finished. However, in practice, it is often only possible to track part of the trajectory. At step 76 the data obtained thus far is compared to an imperical model to compute the full trajectory of the golf ball when data is only available relating to part of the trajectory.

The actual distance that a golf ball travels through air is related, *inter alia*, to the launch speed in the direction of movement, the vertical and horizontal launch angles, the spin rate and direction (spin vector), the mass of the ball, the dynamic drag coefficient Cd_o and the dynamic lift coefficient CL_o (taking into account the current actual spin vector, wind, air temperature and other atmospheric conditions).

At step 78 the carry distance of the ball is displayed on the display 7 of the enclosure 1. At step 80 the launch velocity of the ball is displayed. At step 82 the club strike speed is displayed

This data is displayed usually within four seconds of the ball being struck.

The above processes will now be further described with reference to Figure 13.

Step 1

Process raw data to determine radial speed, Vr, and elevation angle, ϕ, measured by the radar.

Step 2

Use two first order polynomial fittings on Vr to find the starting point and to extract the good data (i.e. remove values not belonging to the golf ball trajectory).

Step 3

Extract the real speed, V, and the angle, θ, by using an iteration formula. To initiate the process, use the initial values $\theta = 18^{\circ}$ and $v = v_r$ and then iterate 30 times:

(t = time elapsed since t_o, g is gravity)

$$\Delta r = v\Delta t$$
$$\Delta x = \Delta r\cos(\theta)$$
$$\Delta y = \Delta r\sin(\theta)$$

$$\theta = \arctan\left[\frac{\dfrac{\Delta y}{\Delta x} - \dfrac{y - h}{x + d}}{1 + \dfrac{\Delta y}{\Delta x}\left(\dfrac{y - h}{x + d}\right)}\right] + \phi$$

$$v = v_r \sec(\theta - \phi)$$

Step 4

Extract the drag coefficient, μ, and the lift coefficient, γ, by fitting 5th order polynomials to the horizontal and vertical speed components. The speed components are given by $\dot{x} = v\cos(\theta)$ and $\dot{y} = v\sin(\theta)$.

Once the polynomial coefficients $\{\alpha_i\}$ and $\{\beta_i\}$ such that

$$\dot{x}(t) = \alpha_1 + 2\alpha_2 t + 3\alpha_3 t^2 + \ldots + 6\alpha_6 t^5$$
$$\dot{y}(t) = \beta_1 + 2\beta_2 t + 3\beta_3 t^2 + \ldots + 6\beta_6 t^5$$

are known, calculate the coefficients with the formula

$$\begin{bmatrix}\mu \\ \gamma\end{bmatrix} = \frac{1}{\beta_1^3 + \alpha_1^3}\begin{bmatrix}\alpha_1 & \beta_1 \\ \beta_1^2 & -\alpha_1^2\end{bmatrix}\begin{bmatrix}-2\alpha_2 \\ -2\beta_2 - g\end{bmatrix}$$

Step 5

Estimate horizontal distance travelled. This function uses a numerical solution of the model.

$$\ddot{x} = -\mu\dot{x}^2 - \gamma\dot{y}$$
$$\ddot{y} = -\mu\dot{y}|\dot{y}| + \gamma\dot{x} - g$$

with the difference formulas

$$x_{i+1} - 2x_i + x_{i-1} = -\mu(x_{i+1} - x_i)(x_i - x_{i-1}) - \frac{\Delta t}{2}(y_{i+1} - y_{i-1})$$

$$y_{i+1} - 2y_i + y_{i-1} = -\mu(y_{i+1} - y_i)|y_i - y_{i-1}| + \frac{\Delta t\gamma}{2}(x_{i+1} - x_{i-1}) - g\Delta t^2$$

which can be written in matrix form as

$$\begin{bmatrix} x_{i+1} \\ y_{i+1} \end{bmatrix} = \frac{1}{d} \begin{bmatrix} 1+\mu|y_i - y_{i-1}| & -\frac{\gamma\Delta t}{2} \\ \frac{\gamma\Delta t}{2} & 1+\mu(x_i - x_{i-1}) \end{bmatrix} \begin{bmatrix} b_1 \\ b_2 \end{bmatrix}$$

where

$$d = [1+\mu(x_i - x_{i-1})][1+\mu|y_i - y_{i-1}|] + \left(\frac{\gamma\Delta t}{2}\right)^2$$

$$b_1 = 2x_i - x_{i-1} + \mu x_i (x_i - x_{i-1}) + \frac{\gamma\Delta t}{2} y_{i-1}$$

$$b_2 = 2y_i - y_{i-1} + \mu y_i |y_i - y_{i-1}| - \frac{\gamma\Delta t}{2} x_{i-1} - g\Delta t^2$$

The initial values v and θ are needed to estimate x_1 *and* y_1 as follows:

$$x_1 = \alpha_1 \Delta t + \alpha_2 \Delta t^2$$
$$y_1 = \beta_1 \Delta t + \beta_2 \Delta t^2$$

where

$$\alpha_1 = v\cos(\theta)$$
$$\beta_1 = v\sin(\theta)$$
$$2\alpha_2 = -\mu\alpha_1^2 - \gamma\beta_1$$
$$2\beta_2 = -\mu\beta_1^2 + \gamma\alpha_1 - g$$

Figure 11 shows the vertical and horizontal trajectory information as a function of time. This trajectory information together with a velocity waterfall of Figure 10 is used to compute the ball trajectory and all associated ballistic perimeters, required to model the ball movement through space.

The device of the embodiment uses microwave frequency radiation, but any electromagnetic, acoustic or other wave-like energy could be used.

CLAIMS:

1. A method of analysing movement of a golf ball, the method including transmitting radiation towards a location expected to lie in the path of a golf ball; receiving reflected radiation and generating a signal representative thereof; processing the signal to derive a value indicative of the velocity of the golf ball in a predetermined direction; processing the signal to derive a value indicative of angular deviation of the golf ball trajectory from the predetermined direction; and deriving from the velocity and deviation values an indication of the speed of the golf ball along its trajectory.

2. A method according to claim 1, wherein the velocity of the golf ball in a predetermined direction is determined by measuring Doppler shift of the radiation.

3. A method according to claim 1 or 2, wherein the step of receiving radiation includes receiving radiation from at least two directions parallel to an axis.

4. A method according to claim 3, including receiving radiation from at least one direction parallel to a further axis, different from the other axis.

5. A method according to claim 3 or 4, including analysing a signal generated by the received radiation and determining the angular deviation of the golf ball from the or each axis.

6. A method according to claim 5, including determining the path length difference of the received radiation.

7. A method according to claim 5 or 6, including determining the phase difference of the received radiation.

8. A method according to any one of claims 1 to 7, wherein means for receiving radiation is provided, being sensitive to radiation substantially within a 20° vertical field and a 10° horizontal field.

9. A method according to any one of claims 1 to 8, wherein means for receiving radiation is provided, being substantially 190mm above ground level and between 3.3 and 3.5m behind the expected golf ball launch position.

10. A method according to any one of claims 1 to 9, including detecting when the golf ball is struck by a golf club.

11. A method of analysing movement of a golf ball, substantially as hereinbefore described with reference to and/or as illustrated in any one of or any combination of the accompanying drawings.

12. Apparatus for analysing movement of a golf ball, the apparatus including means for transmitting radiation towards a location expected to lie in the path of a golf ball; means for receiving reflected radiation and ~~generating a signal representative thereof; means for~~ processing the signal to derive a value indicative of the

velocity of the golf ball in a predetermined direction; means for processing the signal to derive a value indicative of angular deviation of the golf ball trajectory from the predetermined direction; and means of deriving from the velocity and deviation values an indication of the speed of the golf ball along its trajectory.

13. Apparatus according to claim 12, including means for measuring Doppler shift of the radiation, to determine the velocity of the golf ball in a predetermined direction.

14. Apparatus according to claim 12 or 13, wherein the receiving means receives radiation from at least two directions parallel to an axis.

15. Apparatus according to claim 14, wherein the receiving means receives radiation from at least one direction parallel to a further axis, different from the other axis.

16. Apparatus according to claim 14 or 15, including means for analysing a signal generated by the received radiation and determining the angular deviation of the golf ball from the or each axis.

17. Apparatus according to claim 16, including means for determining the path length difference of the received radiation.

18. Apparatus according to claim 16 or 17, including means for determining the phase difference of the received radiation.

19. Apparatus according to any one of claims 12 to 18, wherein means for receiving radiation is provided, being sensitive to radiation substantially within a 20° vertical field and a 10° horizontal field.

20. Apparatus according to any one of claims 12 to 19, wherein means for receiving radiation is provided, being substantially 190mm above ground level and between 3.3 and 3.5m behind the expected golf ball launch position.

21. Apparatus according to any one of claims 12 to 20, including means for detecting when the golf ball is struck by a golf club.

22. Apparatus for of analysing movement of a golf ball, substantially as hereinbefore described with reference to and/or as illustrated in any one of or any combination of the accompanying drawings.

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22

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Application No: GB 0124133.0
Claims searched: 1-22

Examiner: Mark Sexton
Date of search: 30 August 2002

Patents Act 1977
Search Report under Section 17

Databases searched:

UK Patent Office collections, including GB, EP, WO & US patent specifications, in:

UK Cl (Ed.T): A6D

Int Cl (Ed.7): A63B 69/36

Other: Online: WPI, EPODOC, JAPIO

Documents considered to be relevant:

Category	Identity of document and relevant passage		Relevant to claims
X	WO 01/00285 A1	(FOCALTRON CORPORATION) - see whole document, note particularly figure 1	1, 3-5, 12 & 14-16
X	US 5863255	(MACK) - see whole document	1, 3-5, 12 & 14-16
X	US 5846139	(BAIR ET AL.) - see whole document, note particularly figure 2	1, 3-5, 12 & 14-16
X	US 5700204	(TEDER) - see whole document	1-5, 10, 12-16 & 21
X	US 5626526	(PAO ET AL.) - see whole document, note particularly the figures	1, 3-5, 12 & 14-16
X	US 5486002	(WITLER ET AL.) - see whole document, note particularly column 10 line 49 - column 12 line 25	1-5 & 12-16
X	US 5481355	(IIJIMA ET AL.) - see whole document	1-5 & 12-16
X	US 5401026	(ECCHER ET AL.) - see whole document	1-5 & 12-16

X	Document indicating lack of novelty or inventive step	A	Document indicating technological background and/or state of the art.
Y	Document indicating lack of inventive step if combined with one or more other documents of same category.	P	Document published on or after the declared priority date but before the filing date of this invention.
&	Member of the same patent family	E	Patent document published on or after, but with priority date earlier than, the filing date of this application.